ESTCP
Cost and Performance Report

(ER-200825)

In Situ Wetland Restoration Demonstration

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This Cost and Performance Report has been prepared to summarize the outcomes of Environmental Security Technology Certification Program (ESTCP) Project ER-200825: In Situ Wetland Restoration Demonstration. This report summarizes qualitative and quantitative performance objectives, pre-demonstration testing, implementation of the demonstration project, and performance monitoring data. In addition, this report covers performance assessment criteria and methods, evaluation of demonstration results, cost, potential implementation issues, and uncertainties associated with the findings.

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ACRONYMS AND ABBREVIATIONS

AC	activated carbon
AECOM	AECOM Technology Services
AFCEE	Air Force Center for Engineering and the Environment
APG	Aberdeen Proving Ground
ARAR	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
BAZ	biologically active zone
BC	black carbon
CCSA	Canal Creek Study Area
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	contaminant of concern
CWA	Clean Water Act
DDD	Dichloro-Diphenyl-Dichloroethane
DDE	Dichloro-Diphenyl-Dichloroethylene
DDT	Dichloro-Diphenyl-Trichloroethane
DDx	Total DDT, i.e. the sum of DDT, DDE, and DDD
DoD	Department of Defense
DON	Department of Navy
ENR	enhanced natural recovery
ERDC WES	Engineer Research and Development Center Waterways Experiment Station
ESTCP	Environmental Security Technology Certification Program
IDW	investigation-derived waste
ITRC	Interstate Technology and Regulatory Council
NA	not applicable
NAVFAC ESC	Naval Facilities Engineering Command Engineering Service Center
NAVFAC EXWC	Naval Facilities Engineering and Expeditionary Warfare Center
NAVFAC LANT	Naval Facilities Engineering Command Atlantic Division
NPV	net present value
NRC	National Research Council
OSWER	Office of Solid Waste and Emergency Response
PAC	powdered activated carbon
PCB	polychlorinated biphenyl
PED	polyethylene device

POM	polyoxymethylene
TBC	to be considered
TOC	total organic carbon
UNH	University of New Hampshire
USACE	U.S. Army Corps of Engineers
USC	United States Code
USEPA	U.S. Environmental Protection Agency

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EXECUTIVE SUMMARY

This Cost and Performance Report has been prepared to summarize the outcomes of ESTCP Project ER-200825: In Situ Wetland Restoration Demonstration. This report summarizes qualitative and quantitative performance objectives, pre-demonstration testing, implementation of the demonstration project, and performance monitoring data. In addition, this report covers performance assessment criteria and methods, evaluation of demonstration results, cost, potential implementation issues, and uncertainties associated with the findings.

OBJECTIVES OF THE DEMONSTRATION

The objective of this project was to field demonstrate and validate activated carbon (AC) in situ wetland remediation technologies, which have been designed to sequester contaminants in wetlands without adversely impacting the ecology of these systems. Remediation of wetlands soils impacted by contamination presents unique challenges due to the desire to preserve hydric soil structure and the presence of sensitive ecological receptors. Traditionally, wetland remediation has relied on physical removal and off-site disposal of hydric soils, which can destroy habitat and create restoration challenges. This project demonstrates a less aggressive, more sustainable, and cost-effective remediation approach than physical removal and off-site disposal.

The Field Demonstration was performed at Canal Creek, Aberdeen Proving Ground (APG), Aberdeen, Maryland. Specific objectives of the demonstration include: evaluate the ability of AC to reduce the bioavailability of (and risks associated with exposure to) polychlorinated biphenyls (PCB) in wetland habitats at the Canal Creek site using a variety of AC delivery systems; provide cost performance data; obtain regulatory agency and trustee acceptance; and generate and disseminate lessons learned. Performance objectives were generally achieved by the demonstration project, although there is some uncertainty in the final results.

TECHNOLOGY DESCRIPTION

The in situ remediation technology evaluated in this study used engineered sequestration agents containing AC to reduce the bioavailability and toxicity of PCBs in hydric soils. Sequestration agents were mechanically deployed over the surface of a wetland and allowed to naturally integrate into the surface layer of the hydric soil through natural mixing processes (i.e., bioturbation, tidal cycles, root mixing, etc.). Incorporation of sequestration agents into the biologically active zone increases the partitioning of PCBs to the bulk phase and limits PCB bioavailability to benthos.

The field demonstration monitored the performance of three potential AC remediation technologies: two pelletized AC products (AquaBlok® and SediMite™), a powder activated carbon (PAC) slurry (referred to as the Slurry Spray), and an engineered manufactured soil cover system (referred to as the Sand control). Untreated control plots (Control) were used for comparative control purposes. The goal of this approach was risk reduction, not mass removal; therefore, performance was gauged through post-treatment evaluation of reduction in PCB bioavailability.

The efficacy of the technologies on the sequestration of PCBs was assessed via evaluations of PCB pore water and tissue residue concentrations (pre- and post-treatment, and relative to control plots). In addition, the partitioning of PCBs from hydric soils to pore water, and from hydric soil to benthic macroinvertebrate tissue was also evaluated. Ecological monitoring was conducted to assess the extent to which the treatment technologies impacted wetlands vegetation and benthic macrofauna. The uptake of nutrients by plants was also measured for each of the treatment types.

DEMONSTRATION RESULTS

Remediation effectiveness was assessed by measuring changes in the bioavailability of PCBs and bioaccumulation of PCBs through pore water sampling and laboratory bioaccumulation testing. Average concentrations of PCBs in pore water generally decreased following treatment within the Slurry Spray and AquaBlok® treatment plots; however, only the post-treatment results for AquaBlok® were statistically lower than pre-treatment levels. AquaBlok® and Slurry Spray post-treatment pore water concentrations were statistically significantly lower than the post-treatment Control plots. PCB concentrations in benthic tissue generally decreased following treatment within the Sand control, Slurry Spray, and AquaBlok® treatment plots, but only the post-treatment results for AquaBlok® were statistically lower than the pre-treatment levels. Post-treatment tissue concentrations from all four treatments were also arithmetically lower than the post-treatment Control, but only the AquaBlok® and Slurry Spray results were statistically lower than the post-treatment Control plots.

No adverse effects were observed on the benthic infaunal population at the demonstration site, although ecological conditions were such that this metric provided only limited data. No adverse effects on plant community composition or nutrient uptake were observed.

Cost performance analysis suggests that remedial costs typically would range from $60,000/acre to $200,000/acre, which may be 20% to 60% less, on average, than more aggressive remedial approaches.

While the findings of the overall program suggest that additions of AC can sequester PCBs, the field demonstration findings were not conclusive in demonstrating effective reductions in bioavailability. The results of the field demonstration indicate that additional monitoring may be necessary to demonstrate that in situ active remediation by AC can be effective in sequestering hydrophobic organic compounds in contaminated wetland sediments.

IMPLEMENTATION ISSUES

The technologies evaluated in this demonstration project are cost-effective, but challenges in technology delivery were noted during cold weather. Equipment to deploy amendment products in wetland settings is readily available and easily adapted to the task. The in situ technologies evaluated in this program are best suited for use in wetland habitats where: habitat disruption should be minimized; desirable flora or fauna might be harmed by traditional remedial excavation methods; the cost of excavation and disposal are not commensurate with the level of

risk reduction desired; and access to the wetland system (e.g., infrastructure improvements) for sequestration delivery and long-term monitoring are not cost-prohibitive.

The results of the technology demonstration were transferred (and continue to be transferred) to potential end-users via professional conference presentations and posters, internal Navy technology transfers, stakeholder meetings, permitting agency meetings, and multiple presentations to the Army APG team. A co-authored peer-reviewed publication is currently in review at an international journal.

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1.0 INTRODUCTION

The Department of Defense (DoD) ESTCP has funded the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC, formerly Naval Facilities Engineering Command Engineering Service Center [NAVFAC ESC]) and its DoD partners U.S. Army Public Health Command, Naval Facilities Engineering Command Atlantic Division (NAVFAC LANT), Air Force Center for Engineering and the Environment (AFCEE), and Engineer Research and Development Center Waterways Experiment Station (ERDC WES) as well as their contractors AECOM Technology Services (AECOM) and the University of New Hampshire (UNH), to demonstrate and validate an innovative technology for the in situ sequestration of contaminants present in hydric soils of palustrine wetlands (ESTCP Project ER-200825: In Situ Wetland Restoration Demonstration).

This Cost and Performance Report has been prepared to describe the field demonstration including performance objectives, site information, pre-demonstration testing, and activities associated with the actual demonstration. Performance assessment criteria and methods, evaluation of demonstration results, cost, and potential implementation issues are also discussed.

Figure 1. Freshwater tidal wetland.

The Field Demonstration was performed at Canal Creek, U.S. Army Aberdeen Proving Ground (APG), Aberdeen, Maryland (Figure 1). The Canal Creek Study Area (CCSA) is also being used by another ESTCP-funded project team (ER-200835: Evaluating the Efficacy of a Low-Impact Delivery System for In Situ Treatment of Sediments Contaminated with Methylmercury and Other Hydrophobic Chemicals; visit http://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Sediments/ for additional information).

1.1 BACKGROUND

Wetlands often act as sinks for contaminants including persistent, bioaccumulative, and toxic compounds (e.g., polychlorinated biphenyls [PCB]), as well as inorganic constituents (e.g., copper and lead) and energetics from firing range operations. Federal and state agencies mandate that DoD and other responsible parties conduct remedial actions to address contamination in wetlands (e.g., Figure 1). The Navy has more than 200 contaminated sediment sites with projected remediation cost of $1.3 billion; munitions response program sites add another $1 billion of potential liability (Pound, 2012).

Traditional remedial measures in wetlands, such as excavation of hydric soils and off-site disposal, are destructive to hydric soil structure and ecological habitat and are often costly (Kusler, 2006a, 2006b); lower impact alternatives that take advantage of enhanced natural

recovery (ENR) processes are actively being tested, as presented by Patmont et al. (2013), Ghosh et al. (2011), and briefly described in Section 2 of this report.

In situ remedial technologies for wetland systems are similar to subaqueous applications (Renholds, 1998; Reible, 2004; Thompson et al., 2004) with the goal of reducing contaminant bioavailability through amendment addition (Walters and Luthy, 1984; Semple et al., 2003; Di Toro, 2008; Bridges et al., 2008; Zimmerman et al., 2004); however, wetland in situ remediation is complicated by hydric soil structure, wetland hydrology, and the presence of hydrophytic vegetation. Use of high value amendments (e.g., activated carbon [AC]) for in situ restoration may be considered an ENR remedy that includes a long term monitoring component, or enhanced monitored natural recovery.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of ESTCP Project ER-200825 was to demonstrate and validate in situ wetland remediation technologies using remediation technologies that employ sequestration amendments (e.g., AC) designed to sequester contaminants in wetlands without adversely impacting the ecology of these systems. Specific objectives of the demonstration include: evaluate the ability of AC to reduce the bioavailability of (and risks associated with exposure to) PCBs in wetland habitats at the Canal Creek site using a variety of AC delivery systems; provide cost performance data; obtain regulatory agency and trustee acceptance; and generate and disseminate lessons learned. Performance objectives were generally achieved by the demonstration project, as described in the Final Report although there is some uncertainty in the final results.

1.3 REGULATORY DRIVERS

Relevant regulatory drivers for the remediation of wetlands include the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Clean Water Act (CWA), as well a variety of state wetland protection statutes. The CCSA has been subject to considerable remedial investigation under the CERLCA program. As a result of the CERCLA regulatory drivers, a determination has been made that unacceptable risks to human health or the environment may be present in portions of the Canal Creek system.

Innovative technologies, such as the current demonstration, that result in in situ remediation without destroying or functionally altering wetland ecosystems have the potential to result in remediation cost savings with minimal loss of ecological function. These less invasive remediation strategies also align with a wide variety of Federal and state-led green and sustainable remedial approaches.

2.0 TECHNOLOGY

In situ wetland remediation as applied in this project is considered the application of an amendment to the biologically active zone (BAZ) of a wetland in an effort to chemically isolate identified contaminants of concern (COC) from potential ecological and human receptors (Luthy et al., 1997; National Research Council (NRC), 2003; Ghosh et al., 2011). This section describes the in situ sequestration technology, its development, advantages, and limitations.

2.1 TECHNOLOGY DESCRIPTION

The in situ remediation technology evaluated in this study used engineered sequestration agents containing AC to reduce the bioavailability and toxicity of PCBs in hydric soils. Sequestration agents were mechanically deployed over the surface of a wetland and allowed to naturally integrate into the surface layer of the hydric soil through natural mixing processes (i.e., bioturbation, tidal cycles, root mixing, etc.), though the relative importance of each mixing process has not been characterized at this site, nor has the degree of mixing. Given the lack of a benthic macro-infaunal community at the site evaluated in this study, the role of bioturbation is uncertain, and is likely at least partially driven by plant rhizomous root growth. Incorporation of sequestration agents into the BAZ increases the partitioning of PCBs to the bulk phase and limits PCB bioavailability to benthos (Figure 2). The goal of this approach is risk reduction, not mass removal; therefore, performance is gauged through the reduction in contaminant bioavailability following the addition of the sequestration agents.

The appropriate use of this technology begins with identifying the proper sequestration agent to meet required remediation goals of a wetland site. Factors to consider in sequestration agent selection include chemical, physical, biological, geographic, social, and climatic conditions at the site. Agent selection will generally begin with a literature review or relevant engineering experience; however, treatment performance will often need to be demonstrated in the laboratory and/or field prior the final deployment in order to demonstrate adequate risk reduction and to select an appropriate application method. Prior to implementation, performance metrics must be established and monitored to verify that risk reduction is accomplished in a manner and within a timeline consistent with the site-specific remediation goals. The generalized treatment process flow is summarized in Figure 3.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

As discussed in the Final Report, the efficacy of this treatment for reducing bioavailability of PCBs in wetland sediments was not conclusively demonstrated in this project. While the sequestration agents potentially allow targeted in situ remediation of hydrophobic organic contaminants in wetland hydric soils, the data from this demonstration and validation study were not conclusive. Although post-treatment benthic invertebrate tissue concentrations were statistically significantly lower than the pre-treatment concentrations for one treatment (AquaBlok®), the other treatments did not show statistically significant reductions in the bioavailability of PCBs over the time frame evaluated within the project. Although statistically not significant, several other amendments resulted in arithmetically lower pore water and tissue concentrations post-application. Sufficient information was generated to show that AC potentially could provide sequestration without destroying or functionally altering wetland

ecosystems, thus minimizing associated adverse impacts. Additional monitoring is necessary to determine whether this technology is applicable for further use at DoD contaminated wetland sites.

However, it is possible that short-term impacts to hydrophytic flora and fauna may occur. Other potential challenges include the long-term physical stability of the treatment under a variety of climatic and hydrodynamic conditions, differences in sorption behavior due to wetting/drying cycles, implementation related factors (e.g., homogeneous amendment application in uneven terrain, application in areas with limited vehicular access), and other logistical challenges. Full-scale remedial efforts may require more investment in pilot-scale evaluations and post-treatment monitoring than conventional practices because the sequestration agent method of remediating wetland systems is still relatively immature.

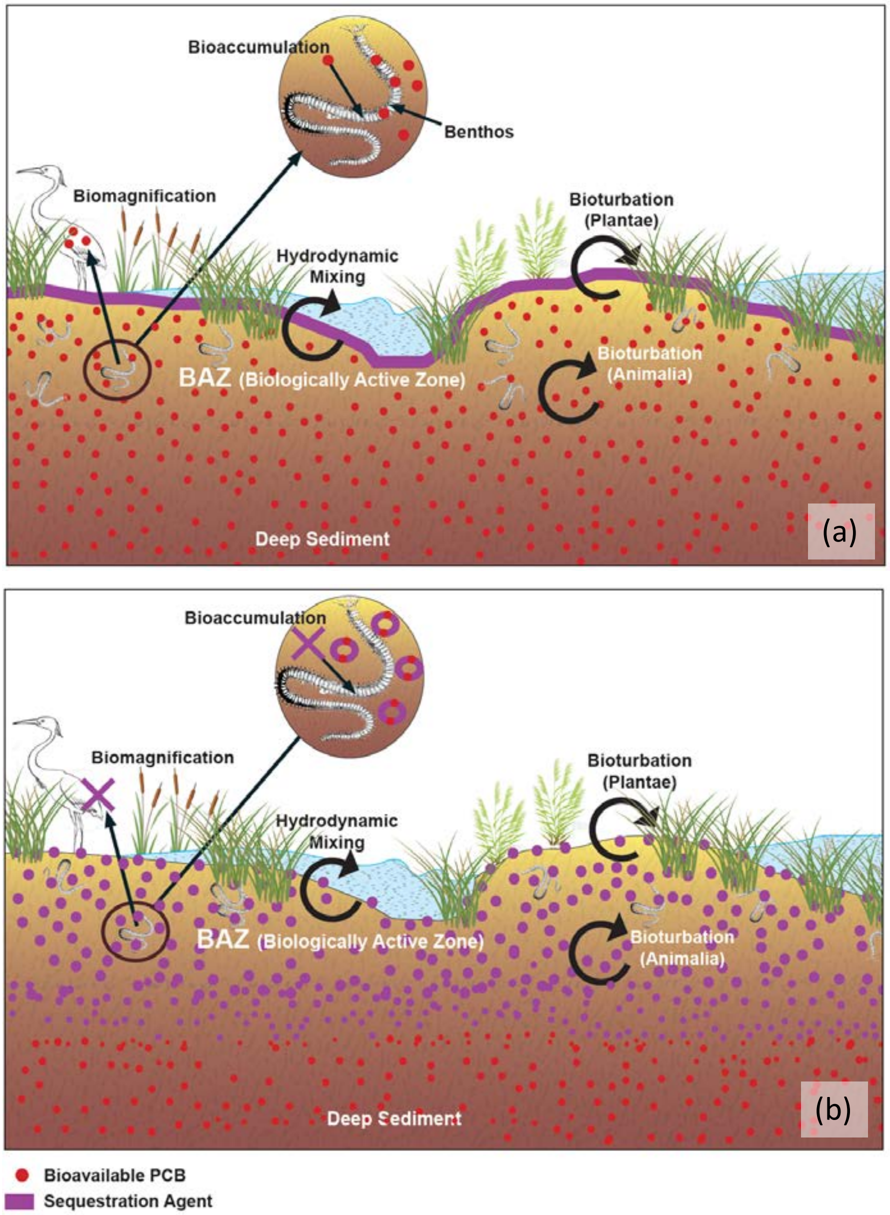

Figure 2. Conceptual model of in situ wetland remediation.
(a) Wetland Immediately Following the Application of Sequestration Treatment
(b) Wetland with Dispersed Treatment Limiting Bioavailability of COCs

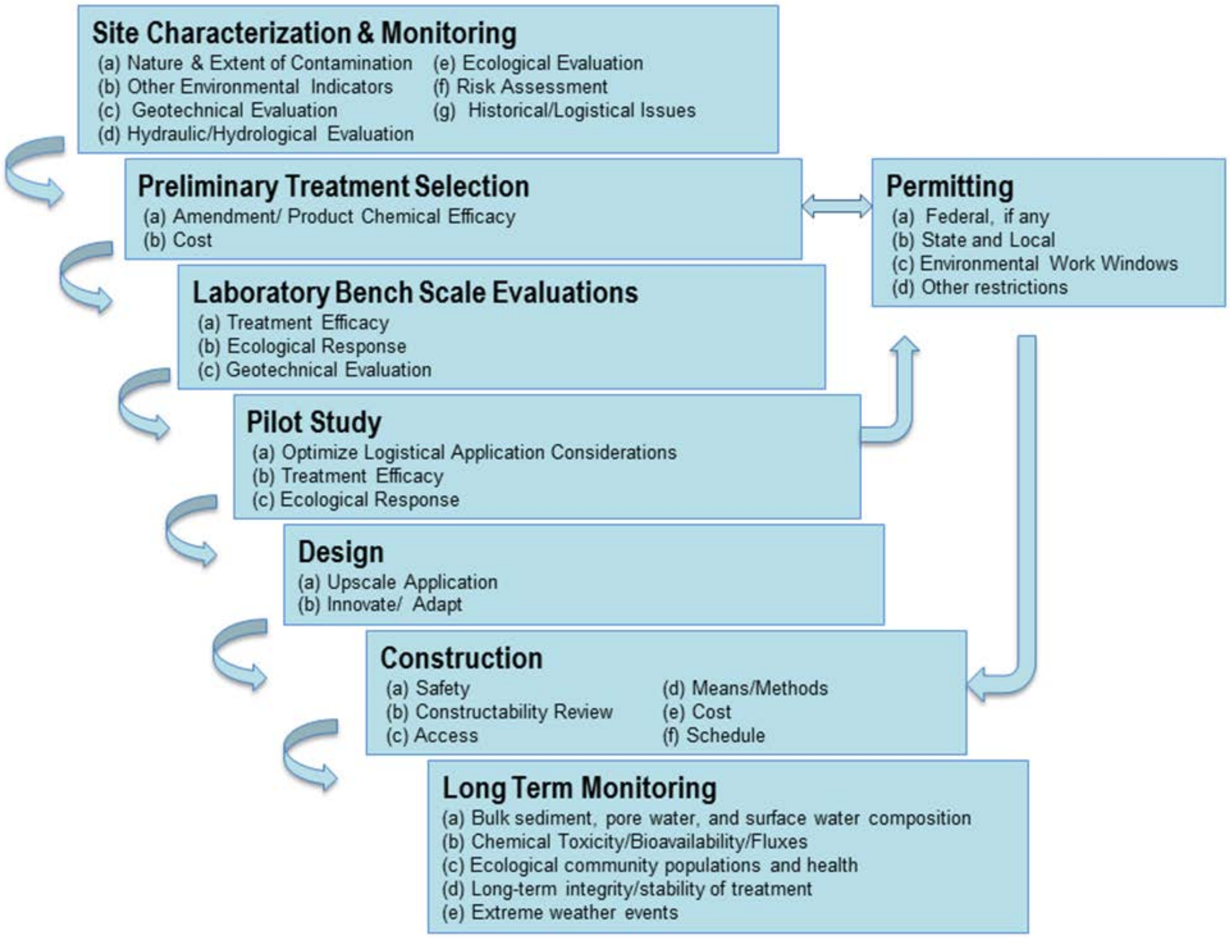

Figure 3. In situ wetland remediation process flow diagram.

3.0 PERFORMANCE OBJECTIVES

Quantitative and qualitative performance objectives were identified for the demonstration and summarized in Table 1. Objectives are discussed in the following sections.

Table 1. Performance objectives.

Quantitative Performance Objective	Data Requirements	Success Criteria	Results
Determine remediation effectiveness in terms of PCB stability and bioavailability	Co-located pore water and tissue residue PCB concentrations in treated plots and control plots	PCB pore water and tissue concentrations significantly reduced in treated plots relative to pre-treatment and control plots	**Porewater PCB Concentrations** • Post-treatment pore water concentrations for one amendment (AquaBlok®) were statistically significantly lower than pre-treatment. • While not statistically significant, other amendments showed arithmetically encouraging trends (i.e., slight reductions were observed for the Slurry Spray and SediMite™ pore water concentrations over time). • Post-treatment pore water concentrations for two amendments (AquaBlok® and Slurry Spray) were statistically significantly lower than the post-treatment Control. • Although not statistically significant, post-treatment pore water concentrations in the SediMite™ and Sand control were also lower than the post-treatment Control. **Tissue (laboratory bioassay) Concentrations** • Post-treatment tissue concentrations were statistically significantly lower than pre-treatment concentrations for one amendment (AquaBlok®). • Although not statistically significant, some reductions were also observed for the Slurry Spray, SediMite™, and Sand control over time. • Post-treatment tissue concentrations were statistically significantly lower than the post-treatment Control for two amendments (AquaBlok® and Slurry Spray). • Although not statistically significant, post-treatment tissue concentrations in the SediMite™ and Sand control were also lower than the post-treatment Control.
Evaluate resident plant community survival and health after treatment	Pre- and post-treatment plant community composition/ diversity surveys	No substantial change to resident plant community	No substantial changes in plant community observed in post-treatment monitoring events.

Table 1. Performance objectives. (continued)

Quantitative Performance Objective	Data Requirements	Success Criteria	Results
Evaluate benthic invertebrate population survival and health post treatment	Pre- and post-treatment invertebrate community composition/ diversity surveys	No substantial changes in resident benthic invertebrate community	No substantial changes in benthic community observed in post-treatment monitoring. However, a paucity of benthic invertebrates limited robust evaluation of success criteria.
Evaluate hydrological conditions after treatment	Hydrological conditions such as water stage, turbidity, and pH of the wetland prior to and after treatment	Application of amendment does not substantially alter wetland hydrology	No substantial changes in wetland hydrology observed in any of the post-treatment monitoring events.
Evaluate whether adding the amendment impacts nutrient uptake into plants	Plant nutrient uptake laboratory study to evaluate growth and tissue nutrient concentrations from plants grown in treated and untreated soil	No substantial reductions in plant nutrient uptake or growth	No substantial deleterious changes in plant nutrient uptake observed in any of the post-treatment monitoring events.
Estimate costs	Detailed cost performance analysis of the implemented technologies	More effective in cost than traditional excavation and off-site disposal technologies	Depending on site-specific circumstances, in situ technologies will prove to be cost effective.
Evaluate the implementability/ constructability of material deployment methods	Visual observations of application homogeneity and measurements of sequestration agent thickness Observations on site-specific constraints that might affect scalability of technology	Homogeneity of application – homogeneous/ consistent sequestration agent coverage over area (both vertical and horizontal) Scalability – scalable to full scale	Homogeneity of application - Yes Scalability - Dry broadcast application method likely limited for large treatment areas.
Evaluate safety related issues	Documentation of safety related incidents and observations during field implementation	No safety hazard associated with technology implementation	No safety hazards were noted.

Table 1. Performance objectives. (continued)

Quantitative Performance Objective	Data Requirements	Success Criteria	Results
Assess agency and industry acceptance of the technology	Work plan review by agencies and/or trustees	Technology considered acceptable by state or Federal regulatory agency as a remedial alternative Technology considered acceptable by industry as a remedial alternative	Uncertain. While environmental permitting authorities approved this project, no regulatory oversight was conducted. A recently issued USEPA OSWER directive for use of amendments at sediment Superfund sites (USEPA, 2013) suggests general regulatory acceptance.
Transfer technology to potential end-users	Conference presentations and/or journal articles	Presentation at conference or in journal; presentations to DoD end users	Completed.

OSWER = Office of Solid Waste and Emergency Response
USEPA = U.S. Environmental Protection Agency

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4.0 SITE DESCRIPTION

The CCSA at APG is located in southeastern Baltimore County and southern Harford County, Maryland. Canal Creek is situated between the Gunpowder River to the west and the Bush River to the east. The demonstration site is located along the West Branch of Canal Creek, a freshwater creek, just above Hanlon Road (Figure 4).

The West Branch originates as a non-tidal stream, which becomes a meandering tidal creek downstream of Magnolia Road. The creek is bordered by 45 acres of tidal marsh emergent vegetation with small areas of scrub-shrub and forested wetlands. The marsh forms several infrequently flooded side arms. The West Branch has been the site of extensive historic discharge of wastes and also receives inputs from contaminated groundwater via seeps.

PCBs, DDx[1], mercury, and other metals were identified as the primary compounds of potential concern at the CCSA (U.S. Army, 2008); a 2008 field sampling event confirmed historical results, which are discussed in detail in the *Site Selection Memorandum* (NAVFAC ESC, 2009a). Soil sampling conducted in 2009 prior to the demonstration identified elevated concentrations of PCBs along the eastern side of Canal Creek (Figure 5), and sporadic occurrence of DDx in the study area (NAVFAC ESC, 2009b). The PCB concentrations ranged four orders of magnitude, demonstrating a high degree of heterogeneity in the magnitude and spatial distribution of PCBs across the site. Total organic carbon (TOC) levels in soil ranged from 1.1% to 4%, and averaged 2.2% (NAVFAC ESC, 2009b). Several lines of evidence suggest that the PCBs in the CCSA are bioavailable: PCBs are present in fish tissue, estimated pore water PCB concentrations are in excess of USEPA Region 3 surface water screening values, and the potential for food chain impacts to wildlife receptors exists.

Portions of the study area are dominated by a virtual monoculture of *Phragmites australis* (common reed), which is considered an invasive species in most of the eastern states along the Atlantic Coast (http://plants.usda.gov). Much of the CCSA is covered with a diverse riverine tidal freshwater marsh system dominated by a variety of forbes and graminoid species, including cattail (*Typha latifolia*), arrowhead (*Sagittaria latifolia*), rushes (*Juncus* spp.), sedges (*Carex* spp.), wool grass (*Scirpus cyperinus*), pickerelweed (*Pontedaria cordata*), and swamp rose mallow (*Hibiscus palustris*). The more diverse wetland includes deep emergent marsh, shallow emergent marsh, and cattail communities. Figure 6 presents the distribution of wetland vegetative cover types.

[1] DDx refers to Dichloro-Diphenyl-Trichloroethane (DDT) and its breakdown products, Dichloro-Diphenyl-Dichloroethane (DDD) and Dichloro-Diphenyl-Dichloroethylene (DDE).

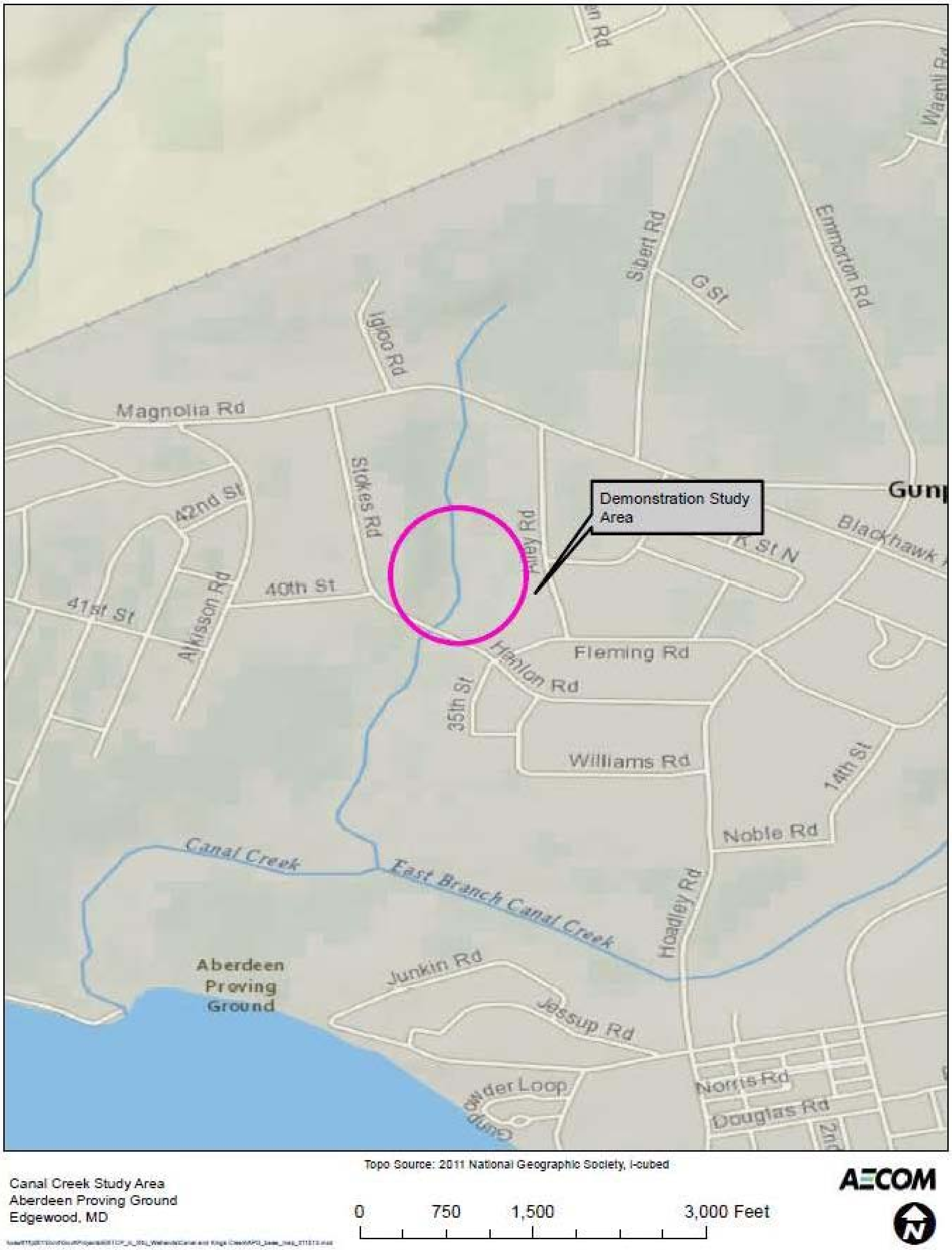

Figure 4. Canal Creek study area.

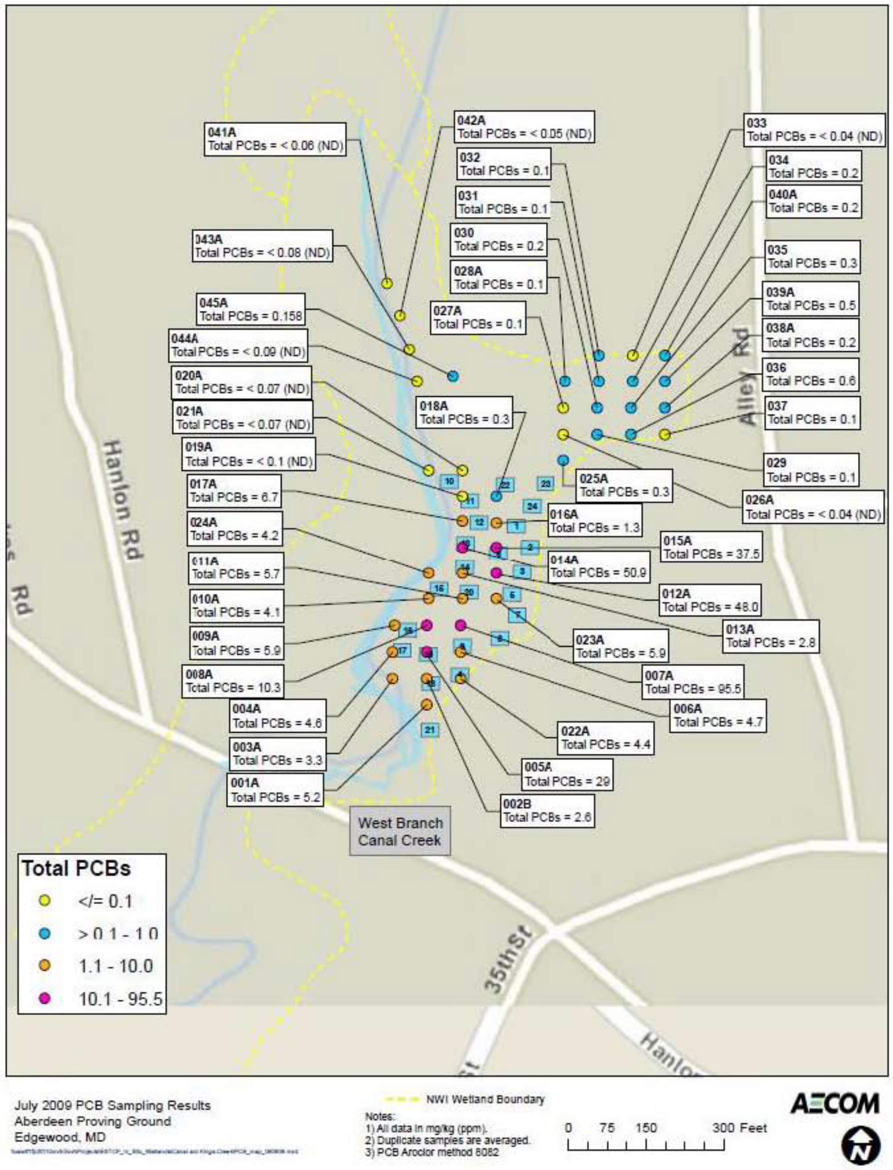

Figure 5. July 2009 PCB sampling results.

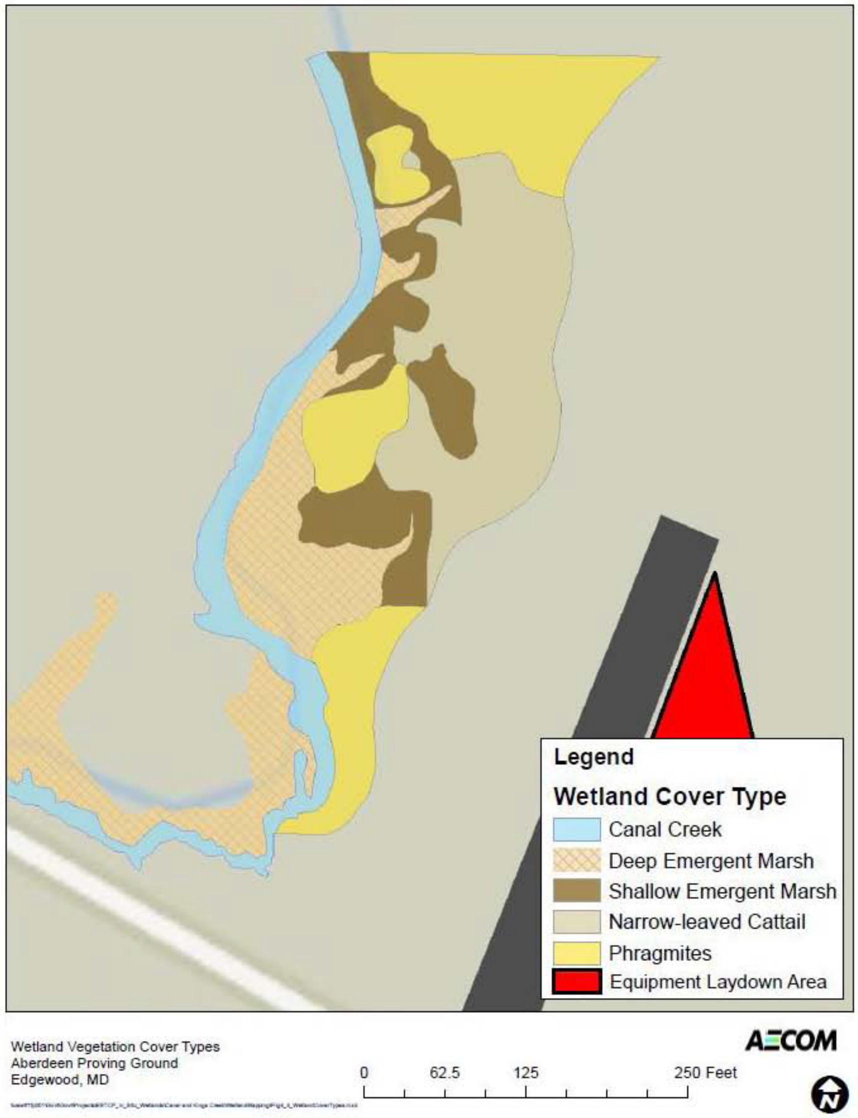

Figure 6. Wetland vegetation cover types.

5.0 TEST DESIGN

This section provides a detailed description of the demonstration design and the pre- and post-treatment testing conducted to address the performance objectives.

5.1 TREATABILITY STUDY RESULTS

To support the field demonstration, focused laboratory treatability testing was performed with CCSA hydric soils to screen several engineered sequestration agents and one dechlorination agent. The treatability testing design and results are presented in the work plan (NAVFAC ESC, 2009c) and study report (NAVFAC ESC, 2009d). The results of the Treatability Study indicated that amendment with 3% AC by weight is the most appropriate amendment choice for the demonstration (NAVFAC ESC, 2009d).

5.2 CONCEPTUAL EXPERIMENTAL DESIGN

Based on the results of Treatability Study, AC amendments were deployed in the field using two methods: a sprayed slurry and dry broadcasting of pelletized AC. These two delivery systems depend upon naturally occurring mechanisms (e.g., bioturbation, hydrodynamic mixing, and vegetative root/rhizome mixing) to vertically distribute the sequestration agent. A sprayed slurry of powdered activated carbon (PAC) and water was used in areas that are not regularly flooded (e.g., the *Phragmites* wetland) and was delivered using a high solids sprayer at a design thickness of 0.5 centimeter (cm). Two different pelletized AC products (AquaBlok® as AquaBlok®+PAC % [No. 8]: 5% AC; 10% bentonite clay by weight;; and 85% aggregate by weight [Project ER-200825] and SediMiteTM as 50% AC [Project ER-200835]) were dry broadcast to test plots. Design specifications and as-built information is discussed in Section 5.5.

Two types of control plots were included in the demonstration experimental design:

1. Control plots receiving no material application, representing an un-remediated system; and,
2. Sand/soil control plots (referred to as Sand control) receiving an application of a sand cover system consisting of a manufactured soil that was engineered by mixing a loam soil and organic matter to mimic native soil permeability and TOC content.

The demonstration consisted of the following operational phases:

- **Time Zero (Time 0):** baseline characterization, study design and layout, field testing;
- **Time One (Time 1):** post-demonstration monitoring at 6 months post-construction; and
- **Time Two (Time 2):** post-demonstration monitoring at 10 months post-construction.

Table 2 presents a summary of the analytical sampling effort during these three phases of work and Table 3 summarizes the ecological sampling program.

Table 2. Total number and types of samples collected.

Component	Matrix	No. Samples	Analyte	Location
Time 0 Baseline characterization December 2010	Pore water	30	PCBs[1]	1 grab sample per test plot, 10 composite samples from replicate plots[2,3] prior to treatment
	Hydric soil	30	PCBs[4]	1 grab sample per test plot, 10 composite samples from replicate plots[2,3] prior to treatment
	Hydric soil	20	Grain size, TOC, BC, moisture[5]	1 composite per test plot[2]
	L. variegatus	30	PCBs[6]	10 composite samples from replicate plots[2,3] prior to treatment
In situ samplers[7]	Pore water	20	PCBs[7]	1 per test plot[2]
Time 1 Post-treatment monitoring June 2011	Pore water	36	PCBs[1]	1 grab sample per test plot, 12 composite samples from replicate plots[3]
	Hydric soil	36	PCBs[4]	1 grab sample per test plot, 12 composite samples from replicate plots[3]
	Hydric soil	24	TOC, BC, moisture[5]	1 composite per test plot
	L. variegatus	24	PCBs[6]	12 composite samples from replicate plots[3]
Time 2 Post-treatment monitoring October 2011	Pore water	36	PCBs[1]	1 grab sample per test plot, 12 composite samples from replicate plots[3]
	Hydric soil	36	PCBs[4]	1 grab sample per test plot, 12 composite samples from replicate treatments[3]
	Hydric soil	24	TOC, BC, moisture[5]	1 composite per test plot
	L. variegatus	36	PCBs[6]	12 composite samples from replicate treatments[3]

[1] ex situ polyoxymethylene (POM) (Hawthorne et al., 2009) modified EPA 8072.
[2] SediMite treatment plots not sampled.
[3] Composite samples were collected from two plots receiving the same treatment.
[4] EPA 8082A.
[5] American Society for Testing Materials (ASTM) D 422; Gustafsson et al., 1997; Grossman and Ghosh, 2009.
[6] EPA methods EPA 600/R-99/064 and EPA 8082A.
[7] in situ polyethylene devices (PED) (Adams et al., 2007)- deployed April 2010 and recovered October 2011.

Table 3. Ecological monitoring field measurements.

Field Activity	Subject of Monitoring	Measurement	Comments
Time 0 Baseline Characterization	Soil characteristics	Texture, TOC	
	Resident plants	Abundance/Density	Number of individual emergent plants per square meter
		Species diversity (Shannon-Wiener Diversity Index)	Plants identified to lowest practical taxon (typically species)
		Percent areal coverage Daubenmire cover class system (Daubenmire, 1959)	Measured for separate strata
	Invasive exotic plants	Presence and number	Plants identified to lowest practical taxon (typically species). Estimate of distribution and square footage per occurrence
Time 1 Post-treatment monitoring	Same as Time 0	Same as Time 0	Same as Time 0
	Benthic invertebrates[1]	Abundance and diversity of benthic invertebrates	Invertebrates identified to lowest practical taxon in the field
Time 2 Post-treatment monitoring	Same as Time 1	Same as Time 1	Same as Time 1

[1] Benthic invertebrates were sampled during the baseline sampling event but there was a paucity of organisms due to habitat limitations.

5.3 PERMITTING

The permit application process was initiated during remediation design and baseline characterization activities, which are described in the next two sections. The CCSA is a CERCLA site; however, because this project was conducted outside the auspices of CERCLA, the regulatory authorities determined that state and Federal permits were necessary. U.S. Army Corps of Engineers (USACE) assumed the role of lead agency in cooperation with the Maryland Department of Environment. Permitting evaluations determined that, because the amendment is incorporated into the soil by mixing processes with time, its placement in the wetlands does not constitute fill—a finding that may make active in situ remediation a more easily implementable technology for projects of similar scale.

5.4 BASELINE CHARACTERIZATION

Pre-treatment monitoring (chemical analyses, laboratory bioaccumulation testing, and ecological evaluations) was conducted to establish baseline conditions within the wetlands. Sampling and analysis methods used for baseline characterization activities are the same as those used for the post-amendment application evaluations that are summarized on Table 2 and Table 3.

Time 0 monitoring was conducted during two events, November 2009 and December 2010. The site area was cleared for unexploded ordnance before work areas were established. Twenty-four test plots, each 8 meters by 8 meters, were staked out (Figure 7) and numbered. Temporary

sediment control products (e.g., 15-cm diameter straw wattles) were placed around the perimeter of each plot, temporary plywood walkways were established between plots as access points, and the plot ecology was characterized. Hydric soil grab samples collected in the top 6 inches of soil in December 2010 were characterized for parameters identified in Table 2.

Figure 7. Cleared test plots, staked sediment control products, and temporary walkways.

Pre-treatment sampling results are presented in Section 5.8.

5.5 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

Table 4 summarizes the AC treatment design for the test plots. As depicted in Figure 8, a series of 8 meter by 8 meter plots were established in the PCB-contaminated region of the CCSA.

5.6 FIELD DEMONSTRATION

Field implementation was performed from November 29 through December 10, 2010. Figure 9 presents the schedule of activities related to the field implementation of the technology. Material placement methods were selected to be scalable, non- or minimally invasive, and deployable to relatively remote areas in consideration of the variable hydrologic conditions of the tidally-influenced wetland system. Table 4 summarizes the thickness of placed amendment, method of deployment, and total quantity placed. Post-demonstration monitoring was conducted 6 months and 12 months after amendment application.

Table 4. AC treatment design and as-built summary.

	Percent AC (by weight)	Design Mass Loading	Design Application Thickness	Measured Application Thickness	Deployment Method	Total Quantity Placed
AquaBlok®	5%	1.9 kg/m^2	5.5 cm (2.2 inches)	5.4 ± 0.5 cm (2.14 ± 0.2 inches)	FINN model BB705 bark blower	26 tons
SediMite[TM, 1]	50%	4.5 kg/m^2	0.3 cm (0.8 inches)	0.25 cm (0.5 inches)	Vortex spreader	2,560 pounds
PAC Slurry Spray	30-50%	2.1 kg PAC/m^2 0.3-0.5 kg PAC / liter of water	Sub-millimeter	thin veneer	FINN model T75 hydro-seeder	1,250 pounds
Sand Control	0%	1.9 kg/m^2	5.0 cm (2.0 inches)	5.1 ± 0.5 cm (1.99± 0.2 inches)	bark blower; manually during cold weather	12 tons

[1] SediMiteTM design includes a 25% safety factor (Field Documentation Work Plan ESTCP Project No. ER-200835, July 2009).
Sand control = manufactured soil cover system
kg/m^2 = kilogram per square meter

5.7 SAMPLING METHODS

The locations, timing, media sample, analyses, and methods are summarized in Tables 2 and 3. In addition, a plant nutrient study was conducted by exposing Japanese millet (*Echinochloa crusgalli*) plant seedlings to soil from three treated plots collected at Time 1 and one laboratory control. Statistics were conducted on the results of the plant health metrics, plant tissue concentrations, and uptake factors relative to the laboratory control and the untreated plot (APG-15 Site Control) results.

5.8 SAMPLING RESULTS

Standard statistical analysis (e.g., Analysis of Variance, t-test) were used to evaluate the statistical significance of changes in bulk hydric soil PCB and BC concentrations, dissolved pore water PCB concentrations, and receptor tissue PCB concentrations, from 28-day bioaccumulation studies. Statistical significance was determined at the alpha = 0.05 level.

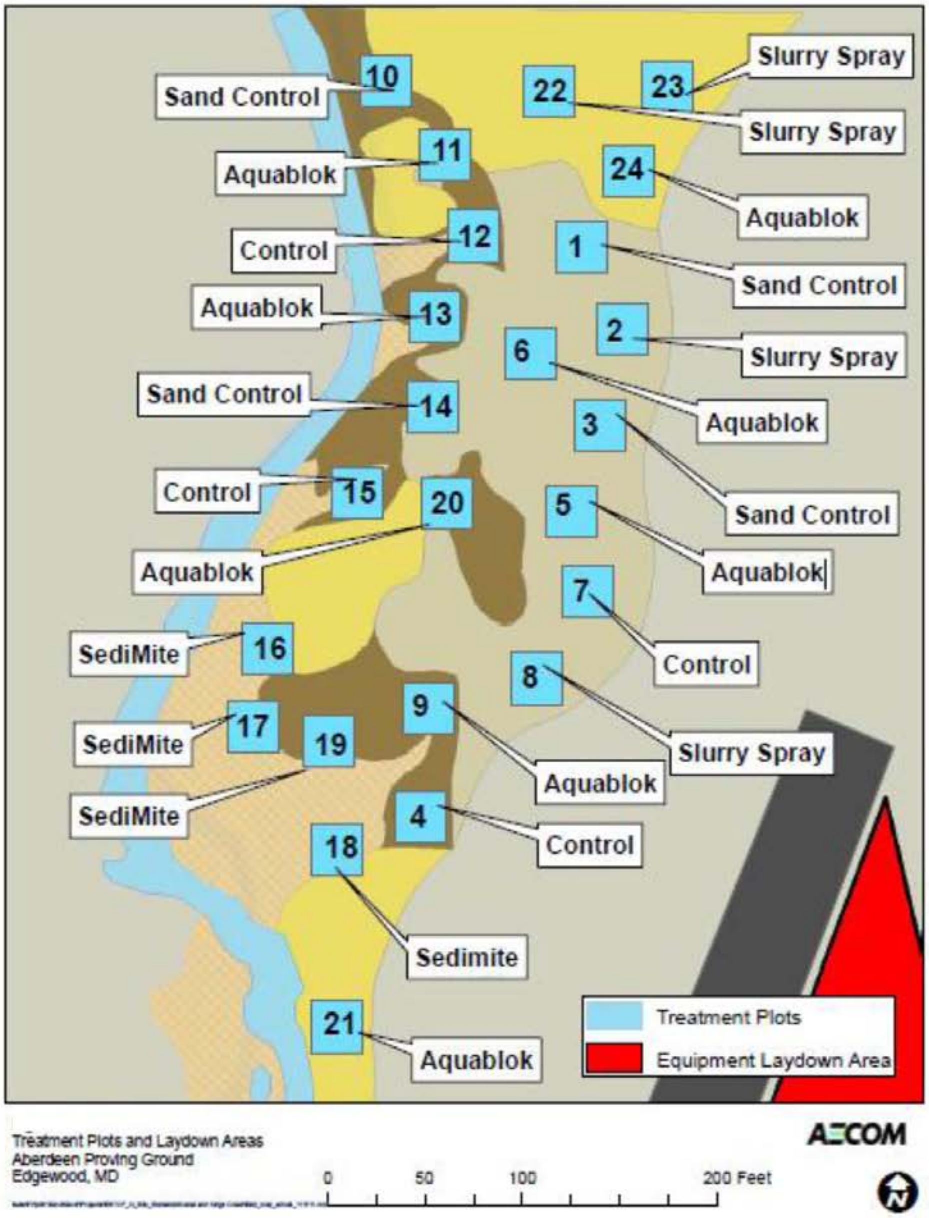

Figure 8. Treatment plots and laydown areas.

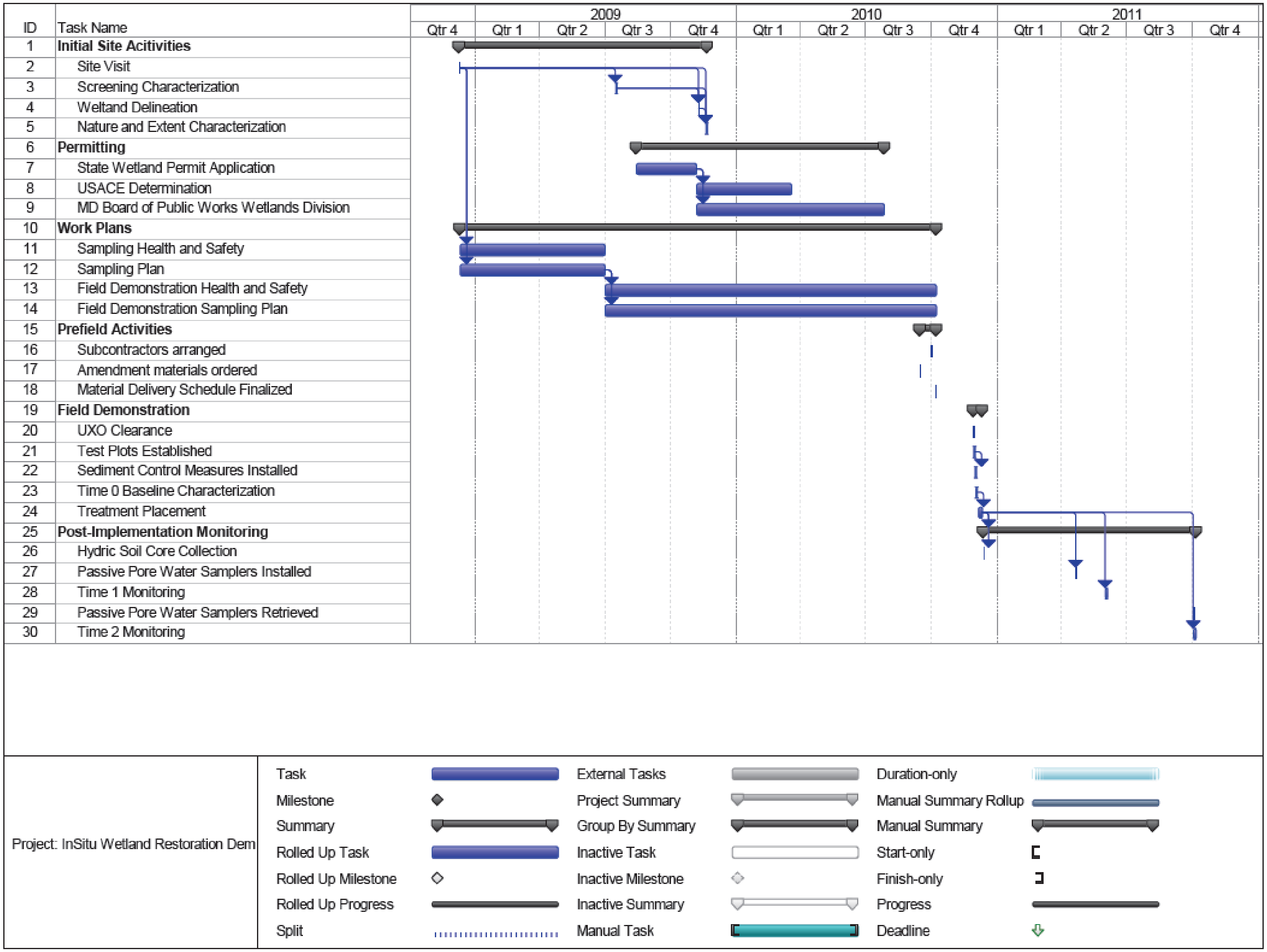

Figure 9. Field demonstration schedule.

5.8.1 Measured Concentrations

Bulk hydric soil PCB concentrations were heterogeneous within the study area pre- and post-treatment, with mean concentrations ranging over two orders of magnitude (Table 5). A weekly statistically significant increase in total PCBs was observed between pre-treatment and post-treatment soil samples (population of all treatments pooled). This suggests the potential introduction of a sampling / analysis artifact.

Table 5. Bulk hydric soil total PCB concentrations.

Treatment	Summary Statistic	Time 0 (mg/kg)	Time 1 (mg/kg)	Time 2 (mg/kg)
Slurry Spray	Mean	1.86E+00	3.39E+00	5.68E+00
	Std. Dev	3.43E+00	4.84E+00	9.66E+00
AquaBlok®	Mean	2.47E+01	2.66E+01	4.16E+01
	Std. Dev	4.64E+01	7.02E+01	1.31E+01
SediMite™	Mean	1.32E+01	3.15E+01	4.56E+01
	Std. Dev	1.31E+01	6.01E+01	4.47E+01
Sand Control	Mean	1.05E+01	3.71E+01	8.99E+01
	Std. Dev	9.78E+00	5.10E+01	1.08E+02
Control	Mean	1.87E+01	2.16E+01	2.78E+01
	Std. Dev	2.54E+01	3.06E+01	3.70E+01

Pore water PCB concentrations were similarly heterogeneous and ranged over several orders of magnitude prior to and following treatment (Table 6). When compared to baseline conditions (Time 0), pore water PCB concentrations in one treatment, AquaBlok®, were statistically significantly lower post-treatment. In situ pore water concentrations generally increased with depth (see Figure 10).

Table 6. Pore water total PCBs.

Treatment	Summary Statistic	Time 0 (mg/L)	Time 1 (mg/L)	Time 2 (mg/L)
Slurry Spray[1]	Mean	2.47E-05	8.54E-06	1.18E-05
	Std. Dev	2.84E-05	1.00E-05	1.33E-05
AquaBlok®[1,2]	Mean	4.97E-03	4.49E-05	3.82E-04
	Std. Dev	1.17E-02	9.41E-05	1.25E-03
SediMite™	Mean	4.60E-04	7.19E-04	3.99E-04
	Std. Dev	7.42E-04	1.70E-03	7.11E-04
Sand Control	Mean	1.04E-03	5.48E-03	3.32E-03
	Std. Dev	1.72E-03	8.81E-03	4.81E-03
Control	Mean	1.80E-03	9.84E-04	6.91E-03
	Std. Dev	2.69E-03	2.17E-03	1.45E-02

[1] Post-treatment concentrations are statistically significantly lower than the post-treatment Control.
[2] Post-treatment concentrations are statistically significantly lower than pre-treatment.
See Final Report for details.

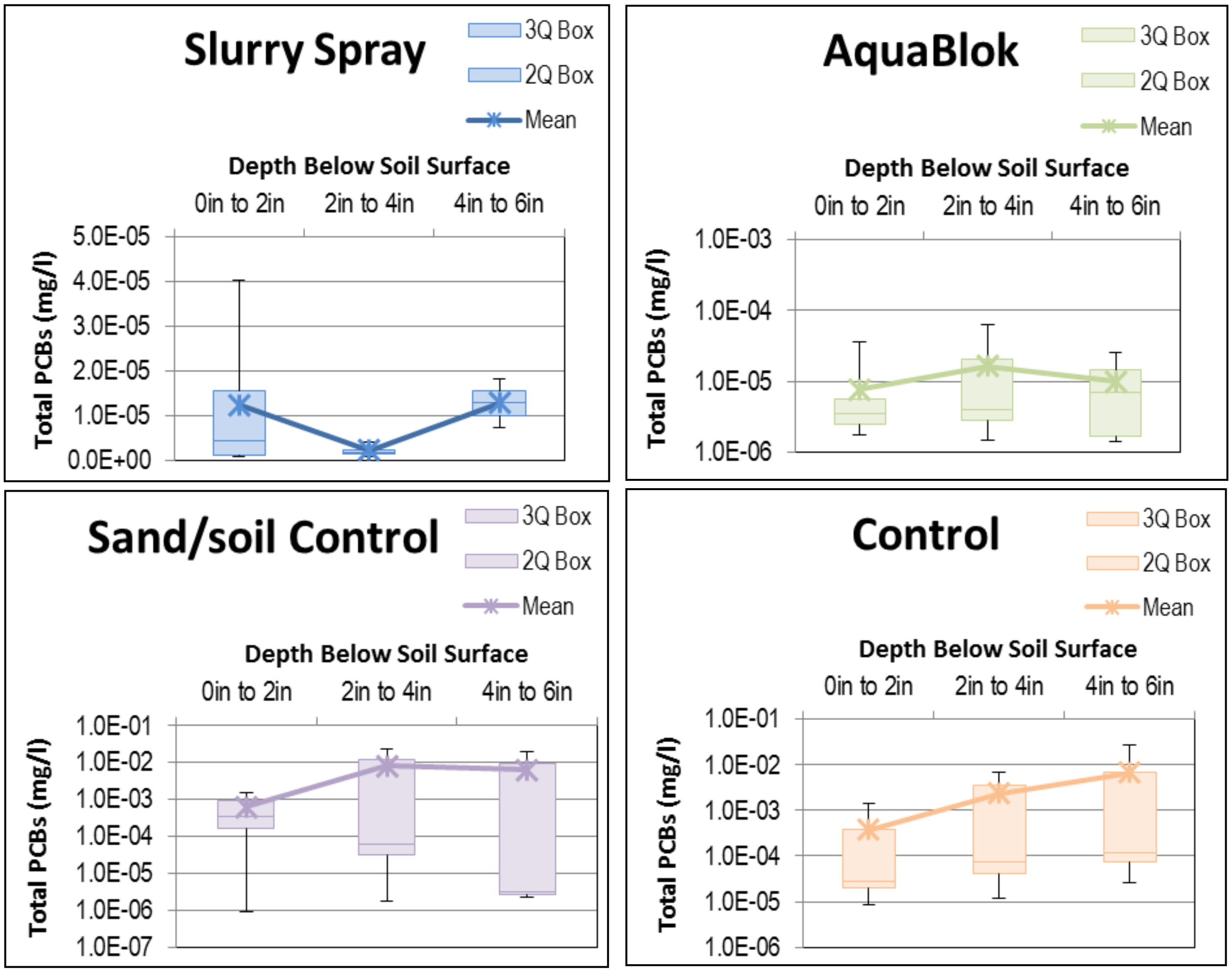

Figure 10. In situ pore water PCB concentration comparison.

Benthic tissue concentrations were also heterogeneous and ranged several orders of magnitude (Table 7). AquaBlok® *Lumbriculus* receptor tissue concentrations were statistically significantly different between pre- and post-treatment data. *Lumbriculus* receptor tissue concentrations in the Slurry Spray and Sand control were arithmetically lower, but not statistically different when post-treatment data were compared to pre-treatment data. Post-treatment AquaBlok® and Slurry Spray *Lumbriculus* receptor tissue concentrations were statistically significantly lower than the post-treatment Control. Time 0 data were not available for SediMite™. Post-treatment tissue concentrations in the SediMite™ and Sand Control treatments were also arithmetically lower than the post-treatment Control.

Table 7. *Lumbriculus* tissue total PCBs results.

Treatment	Summary Statistic	Time 0 (mg/kg)	Time 1 (mg/kg)	Time 2 (mg/kg)
Slurry Spray[1]	Mean Std. Dev	1.65E+00 1.77E+00	2.85E-01 3.52E-01	1.23E-02 1.59E-02
AquaBlok®[1,2]	Mean Std. Dev	1.32E+02 1.86E+02	3.38E-01 4.08E-01	2.09E+00 2.32E+00
SediMite™	Mean Std. Dev	Not Sampled Not Sampled	6.98E+00 6.29E+00	5.34E+00 5.29E+00
Sand Control	Mean Std. Dev	1.45E+01 9.00E+00	2.98E+01 1.94E+01	1.23E+01 1.39E+01
Control	Mean Std. Dev	7.06E+01 1.68E+01	2.40E+01 2.51E+01	2.40E+01 2.51E+01

[1] Post-treatment concentrations are statistically significantly lower than the post-treatment Control.
[2] Post-treatment concentrations are statistically significantly lower than pre-treatment.
See Final Report for details.

Significant heterogeneity (orders of magnitude, in some cases), increasing bulk soil concentrations, and the small sample population size confounded using pore water or tissue trends as the only metrics by which bioavailability reductions were assessed. Therefore, additional analyses of BC and partitioning coefficients were conducted to further evaluate the demonstration project data.

BC was present in the wetlands hydric soil prior to treatment in variable percentages across the study area (Table 8). Slurry Spray and AquaBlok® were the only treatments whose percent-BC concentrations were statistically significantly different between pre- and post-treatment.

Table 8. Black carbon percentages.

Treatment	Summary Statistic	Time 0- December 2010	Time 1- June 2011	Time 2- October 2011
Slurry Spray[1]	Mean Std. Dev	0.65% 0.38%	2.59% 1.81%	2.03% 0.24%
AquaBlok®[1]	Mean Std. Dev	0.96% 0.43%	3.26% 0.78%	1.86% 0.75%
SediMite™	Mean Std. Dev	1.79% 0.58%	3.24% 1.21%	1.36% 0.28%
Sand Control	Mean Std. Dev	0.93% 0.47%	0.52% 0.19%	1.22% 0.77%
Control	Mean Std. Dev	1.47% 0.78%	1.45% 0.90%	0.96% 0.26%

BC percentages are dry weight-based relative to the total sediment sample mass.
[1] Post-treatment concentrations are statistically significantly greater than pre-treatment.
See Final Report for details.

5.8.2 Vegetation Survey

The following key findings were noted in the vegetation survey:

- A total of 49 species were recorded in the wetland.

- A total of 32 species were recorded in the sampling plots.
- Up to 19 species were present within a single plot.
- No significant variation was found between plots containing treatments and control plots in the post application sampling events.
- A significant variation in species richness was observed across all plots between sampling events, likely reflecting seasonal changes in plant community composition (not AC treatment related).

5.8.3 Plant Nutrient Uptake

Boron, calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, sulfur, zinc, nitrogen were measured in soil and plant tissue. Nutrient uptake (measured as the ratio of nutrient concentration in plant to concentration in soil) was typically not statistically significantly different from site control ("—") for any of the nutrients evaluated (Figure 11). Other notable results include:

- Survival at test termination ranged from 97.5% in the laboratory control to 100% in APG-02, APG-06, and APG-16 indicating that the treatments showed no adverse effects on plant survival.
- Similarly, no statistically significant adverse sub-lethal affects were observed for the plant growth endpoints (plant shoot wet weight, plant shoot dry weight, or plant shoot length) relative to the lab control or APG-15 (Site Control) results.
- All three growth metrics in the APG-16 (SediMite™) sample were statistically significantly higher than in the APG-15 (Site Control) sample.

Treatment	B	Ca	Cu	Fe	Mg	Mn	P	K	Na	S	Zn	N
Slurry Spray (APG-02)	↑	↑	↑	---	↑	↑	↑	↑	---	---	↑	↑
AquaBlok® (APG-06)	↑	---	↑	---	↑	---	↑	↑	---	---	↑	↑
SediMite™ (APG-16)	---	↑	---	---	↑	---	---	---	---	↓	---	---

'—' = not statistically significantly different from control; ↑ = statistically significantly higher; ↓ = statistically significantly lower; B = Boron, Ca = calcium; Cu = copper; Fe = iron; Mg = magnesium; Mn = manganese; P = Phosphorus; K = potassium; Na = sodium; S = sulfur; Zn = zinc; N = nitrogen

Figure 11. Plant nutrient uptake.

5.8.4 Benthic Macroinvertebrate Survey

The macroinvertebrate populations were small for each sampling event and considerable uncertainty is associated with analysis of these data; the lack of macroinvertebrates was likely due to habitat limitations in this intermittently flooded wetland system. A total of 71 organisms (representing 13 different taxa) were recovered in the Time 1 sampling event and 19 organisms (representing 5 different taxa) were collected at Time 2 (Figure 12).

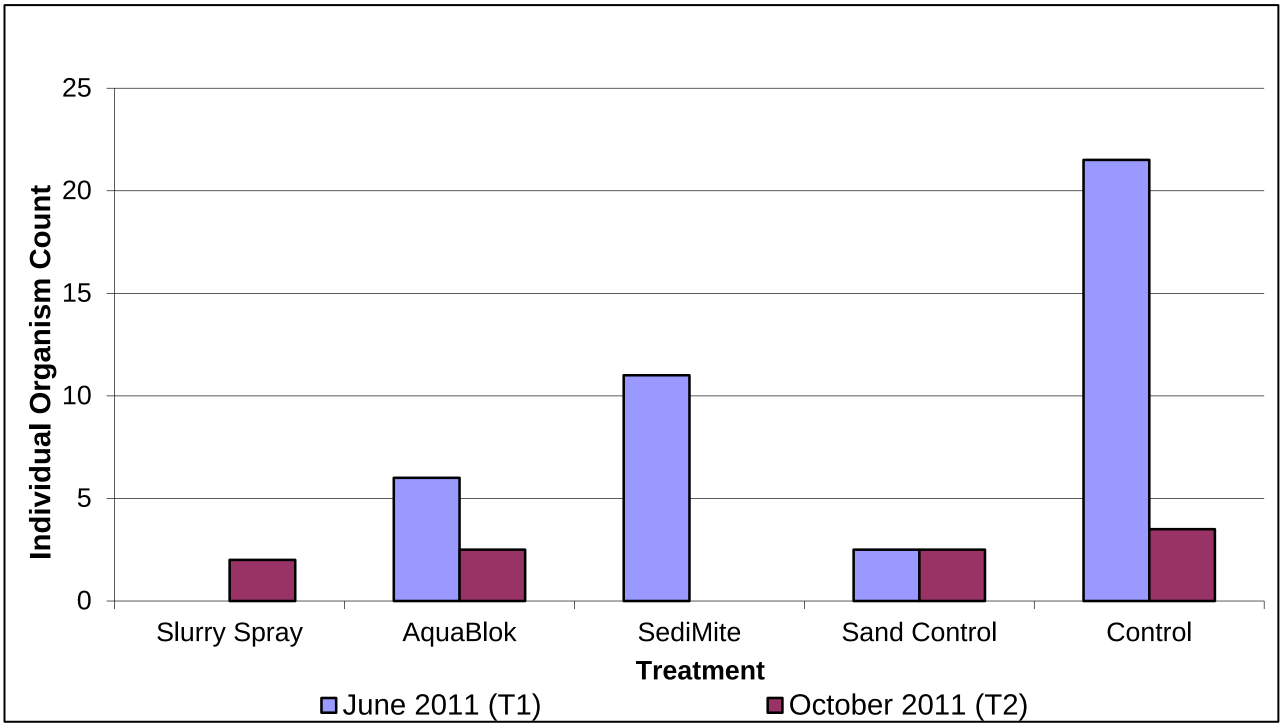

Figure 12. Macroinvertebrate population count by treatment type.

6.0 PERFORMANCE ASSESSMENT

Data were statistically analyzed to identify significant differences between treatments and controls. Data were evaluated based on the success criteria described in Section 3 to determine if the performance objectives of the demonstration were met.

6.1 REMEDIATION EFFECTIVENESS

Remediation effectiveness was assessed by measuring reductions in the bioavailability of PCBs and bioaccumulation of PCBs through pore water sampling and laboratory bioaccumulation testing (Interstate Technology & Regulatory Council [ITRC], 2011). Changes in the partitioning of PCBs from pore water to the bulk solid phase and from macroinvertebrate tissue to the bulk solid phase were also assessed as an additional line-of-evidence to account for the large heterogeneity observed across the treatment site and small sample sizes. A summary of the statistical evaluation of data is presented in Table 9.

Table 9. Statistical analyses summary.

	Evaluation Parameter			
Treatment	**Post-Treatment Statistically Significantly Lower than Pre-Treatment?**	**Post-Treatment Statistically Significantly Different than Control?**	**Post-Treatment Partitioning to Soil Statistically Significantly Greater than Pre-Treatment?**	**Post-Treatment Partitioning to Soil Statistically Significantly Greater than Control?**
Pore water PCB				
Slurry Spray	No	Yes	Yes	No
AquaBlok®	Yes	Yes	Yes	Yes
SediMite™	No	No	No	No
Sand Control	No	No	No	No
Control	No	No	Yes	*NA*
***Lumbriculus* tissue PCB**				
Slurry Spray	Yes	No	Yes	Yes
AquaBlok®	Yes	Yes	Yes	Yes
SediMite™	*NA*	No	*NA*	*NA*
Sand Control	No	No	Yes	No
Control	Yes	No	Yes	No

6.2 ECOLOGICAL EFFECTS

Plant community survival and health, plant nutrient uptake, and benthic invertebrate survival and health were assessed relative to the performance criteria described in Section 3. Ecological results are summarized in Table 10.

Table 10. Summary of ecological effects.

Survey	Result
Vegetation	• No gross effects (early senescence, yellowing, stunting) observed • No statistically significant differences between treatment and control plots in relative vegetation cover or in species richness or diversity
Plant Biological, Toxicological, and Nutrient Metrics	• No statistically significant adverse effects in survival, shoot weight (wet and dry), or shoot length • Nutrient uptake was typically not statistically significantly different from site control (see Table 6).
Benthic Macroinvertebrate	• No conclusions drawn as to effects of treatment due to a paucity of benthic organisms

6.3 PERFORMANCE EVALUATION

The performance of each treatment was assessed by comparing treatment costs to more traditional remedial approaches, implementability based on material application rates, equipment limitations, reliability and scalability, and constructability based on application homogeneity and sequestration agent thickness. A present value cost-savings of greater than 30 to 50% compared to removal and wetland restoration would represent a successful demonstration. Results of the cost analysis are presented in Section 7.3, and show an average projected potential cost savings of 20 to 60% on a per acre basis.

6.4 TECHNOLOGY ACCEPTANCE AND TRANSFER

Thompson et al. (2012) identified the greatest needs to promote active in situ treatment acceptance by stakeholders as a viable remedy are long-term proof of effectiveness and permanence. A recent USEPA OSWER publication (USEPA, 2013) generally endorses the use of amendment technologies and should help with future regulatory acceptance. The acceptance of the technology for ESTCP ER-200825 was assessed via the permitting process, work plan review, and peer-reviewed publications/conference presentations.

- USACE issued a Water Quality Certification permit and determined that the activities did not constitute permanent placement of fill at the project scale.
- The Demonstration Plan was reviewed and approved by state Maryland Wildlife Management Area and Federal (e.g. USACE) agencies prior to implementation.
- SERDP and ESTCP have funded/are currently funding multiple projects that focus on the use of amendments to sediment or to sediment caps to manage contaminated sediments in situ.
- More than 10 technology transfer presentations were completed in a variety of professional forums, as well as with stakeholder and agency groups, in addition to several internal Navy technology transfers.

6.5 SAFETY

Approximately 600 field hours and 1000 laboratory hours in the field and laboratory were injury free. Safety observations were reported during the field activities and investigation-derived waste (IDW) was managed in accordance with the Health and Safety Plan. Observations noted potentially hazardous conditions in the site-specific environment. No activities were modified or stopped due to technology-related hazards.

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7.0 COST ASSESSMENT

Cost tracking and order-of-magnitude costs for full-scale application of technologies were assessed. Tracked costs for the demonstration project are not directly scalable to an implementation project due to the research nature of the demonstration; therefore, a cost model was developed to evaluate scalability to a larger wetland site.

7.1 COST MODEL

Site variables such as the size and type of wetland requiring remediation, access, vegetation conditions, topography, water level conditions, and other site conditions may necessitate a broad variety of approaches in the method and types of deployment equipment for in situ remediation. In order to bracket typical remedial scenarios, example costs were presented for three different size wetland areas (1, 5, and 10 acres). Table 11 presents a cost summary (in U.S. dollars) for the full-scale implementation of this technology assuming the typical scenarios described above, as well as tracked demonstration costs. Design and permitting costs were not included as these costs are assumed to be consistent regardless of the selected remedy (traditional removal vs. in situ sequestration).

7.2 COST DRIVERS

As depicted in Table 11, the primary cost drivers are mobilization/site preparation, amendment materials, demobilization/site restoration, and long-term monitoring costs.

- Mobilization and demobilization costs become less significant to the overall project costs as the application area increases.
- Site preparation/restoration costs are dictated by providing sufficient access for the construction equipment to effectively deploy amendment.
- The type and quantity of amendment required can be a cost driver. The amendment cost was estimated to be ~5 to 12% (1 acre vs. 10 acres) of the total construction cost.
- It is likely that extensive long-term monitoring will be required by regulatory stakeholders for the foreseeable future, given the evolving nature of these technologies. Depending on the nature and duration of the monitoring, costs associated with this effort can be substantial.

7.3 COST ANALYSIS

The cost for a traditional source removal and restoration approach can range anywhere from an estimated \$1.0M to \$2.0M per acre depending on the size/type of wetland, contaminant disposal options (transportation and disposal of excavated media typically comprise a substantive portion of the total cost), depth and type of impacts, and ecological restoration requirements.

Life-cycle costs for the in situ methodologies described herein were calculated using Net Present Value (NPV) costs assuming a 20-year remediation timeframe. Long-term monitoring costs were discounted at a rate of 1.7% (Office of Management and Budget, 2012). The total NPV cost is

projected to range from $170K to $360K per acre (for a 1-acre project), which is consistent with observations of others (Ghosh et al., 2011; Patmont et al., 2013). Thus, the costs run about 20% of traditional removal technologies, providing significant potential savings by employing in situ sequestration methodologies.

Table 11. Tracked cost and cost estimates for in situ contaminant sequestration in wetland hydric soils.

Cost Element	Element Components	Tracked Costs ($K)	Cost per Treatment Area (acres)[1], $K		
			1 Acre	5 Acre	10 Acre
Treatability Study	- Labor - Materials - Analytical Laboratory Costs	$42	$20 - $25	$25 - $50	$25 - $50
Mobilization	- Access Road, Deployment Roads - Shipment of Equipment and Supplies	$28.5	$15 - $70	$50 - $350	$100 - $600
Material Cost[2] (Amendment)	- Material Cost (with manufacturing)	$27.3	$20 - $40 (PAC) $50-$70 (Pellet)[3]	$100 - $200 (PAC) $250-$(Pellet)[3]	$200 - $400 (PAC) $500-$700 (Pellet)[3]
Implementation	- Equipment Rentals - Labor (amendment deployment and application thickness confirmation measurements)	$119.1	$5 - $15	$10 - $40	$15 - $75
Demobilization	- Access Road, Dry/Wet Deployment Roads, Restoration - Shipment of Equipment and Supplies	$10	$15 - $30	$40 - $130	$70 - $275
Long-term Monitoring	- Travel and Labor (sampling and field surveys) - Shipment of Equipment and Supplies - Laboratory Costs	$215	$25 - $50	$100 - $150	$200 - $250
Reporting	- Annual and 5-Year reporting	*NA*	$75 - $100	$75 - $100	$75 - $100
Permitting	- Applications and Plans - Meetings	$15	--		
Professional Services	- Work Plans, Reporting, Management and Dissemination	$306.6	--		

[1] All costs are based on tracked and estimated costs.
[2] Cost of shipping not included because it will vary with quantity and distance from manufacturer/supplier.
[3] with weighting agent.
'—' = Not estimated since anticipated to be approximately the same for all technologies.

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8.0 IMPLEMENTATION ISSUES

8.1 REGULATORY CONSIDERATIONS

This section addresses Federal requirements for working in and around wetland systems. Relevant Federal regulatory drivers include CERCLA, which authorizes USEPA to clean up contaminated sites and to compel responsible parties to perform cleanups or reimburse the government for USEPA-lead cleanups. Other pertinent Federal regulations include: CWA Sections 404 and 401; Endangered Species Act (16 United States Code [USC] Chapter 35); the Migratory Bird Treaty Act (Title 16 USC Sections 703-712); Floodplain development under Executive Order 11988 and the protection of wetlands under Executive Order 11990; Fish and Wildlife Coordination Act (16 USC Chapter 5A); and, the Coastal Zone Management Act (16 USC Section 145). Federal or state water quality standards may be applicable or relevant and appropriate requirements (ARAR) for determining cleanup levels, and if PCBs are present, the Toxic Substance Control Act may apply.

The Federal government is actively pursuing a sustainable approach to all its activities in accordance with Executive Orders 13423 (2007) and 13514 (2009), and the recent Department of Navy (DON) (DON 2012a, b) and DoD (2009) guidances.

Numerous additional to be considered (TBC) regulations are summarized in *CERCLA Compliance with Other Laws Manual* (USEPA, 1988). Depending on site specific needs, some TBC regulations may be ARARs (e.g., National Pollution Discharge Elimination, Resource Conservation and Recovery Act).

8.2 LESSONS LEARNED AND RECOMMENDATIONS

The PCB bioavailability analysis determined that bioavailability was likely reduced by addition of AC to the Canal Creek wetland system. This finding was more apparent in the partitioning evaluations than in the direct measurements of pore water concentration reductions, due to a large heterogeneity in PCB distribution, small sample size, and sampling/analysis artifacts.

A treatment design of 3 to 5% AC is consistent with the results reported in the Treatability Study (NAVFAC ESC, 2009d). The results of the demonstration highlight the challenges of moving a treatment from a controlled environment to uncontrolled environmental conditions. Recommendations include adaptively modifying performance monitoring approach if ambiguous results are initially obtained and conducting long-term monitoring to evaluate treatment permanence.

The technologies evaluated in this demonstration project are cost-effective but challenges in technology delivery were noted during cold weather. The technology is best suited for application to contaminated hydric soils in native wetland habitats where disruption should be minimized; unacceptable risk is not sufficient to justify the cost of aggressive remedial approaches; the infrastructure improvements for implementation are not cost-prohibitive; and where long-term monitoring requirements are not cost-prohibitive (such that removal might merit consideration).

Points of contact for additional information regarding the In Situ Wetland Restoration Demonstration (ESTCP Project Number ER-200825) are provided in Appendix A.

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APPENDIX A

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